

Reduced Dislocation Densities in High Aluminum AlGaN Alloys for Deep Ultra-Violet Light Emitting Diodes

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Motivation—Solid-state light sources emitting at wavelengths between 200nm and 300nm would enable technological advances in many areas such as fluorescence-based biological agent detection, non-line-of-sight (NLOS) communications, water purification, and industrial processing. Over the past year, we have demonstrated light emitting diodes (LEDs) based on alloys of AlGaN in prototype systems for NLOS communications and bio-agent detection. These LEDs are based on the growth of AlN-AlGaN (50-90% Al) buffer layers on sapphire substrates and are transparent to the LED emission. These materials typically have dislocations densities that are 10-100 times higher than the dislocation density of GaN buffer layers on sapphire used in commercial blue (460nm) LEDs. We are investigating ways to lower the dislocation density of these high Al containing materials by controlling the nucleation process on the sapphire substrate.

Accomplishment—Since non-conducting sapphire substrates are used, LED performance in the deep-UV is dependent on achieving good lateral current transport in high Al composition AlGaN alloys. Recent advances in the nucleation of the underling AlN buffer on sapphire have resulted in a 5-10x reduction in dislocation density of the overgrown AlGaN films used in deep UV-LEDs. This has resulted in both an improvement in electron mobility (Fig. 1) as well as an increase in n-type doping efficiency using SiH₄. We have demonstrated n-type conduction in films to 90% Al due to reduced carrier compensation that we have observed in films with higher dislocation density. Figure 2 shows the sheet resistance of LEDs as a function of dislocation density as

measured by x-ray diffraction using a technique described in the *Physical and Chemical Sciences Center Research Briefs 2003*, p. 22. The sheet resistances have been normalized to a thickness of 1μm to allow comparisons between devices with different thicknesses of Si-doped AlGaN. While the Si-AlGaN layer in the LEDs were grown under different conditions, or had different compositions or underlying buffer layers, the resistance is found to be largely correlated to the density of dislocations that have an edge component, and to a lesser extent, dislocations that have a screw component. Realizing a lower dislocation density improves n-type conductivity at higher Al compositions by both improving the electron mobility and increasing the range of electron concentrations that can be achieved. While many factors influence LED performance such as device structure and processing, it is not surprising that the best LEDs we have measured at any wavelength are those where the density of dislocations with an edge component is less than $3 \times 10^{10} \text{ cm}^{-2}$. To date, LEDs have only been tested on films where the dislocation density exceeded $1 \times 10^{10} \text{ cm}^{-2}$.

Significance—The reduction of dislocation density in AlGaN films is expected to improve the LED performance by several mechanisms. An increase in optical power due to reduced ohmic heating with the improved electron transport is expected. Also, an increase in internal quantum efficiency due to lower non-radiative recombination rates typically associated with lower dislocation density should be observed. These improvements will help to move deep UV-LEDs out of prototype units and into fieldable systems.

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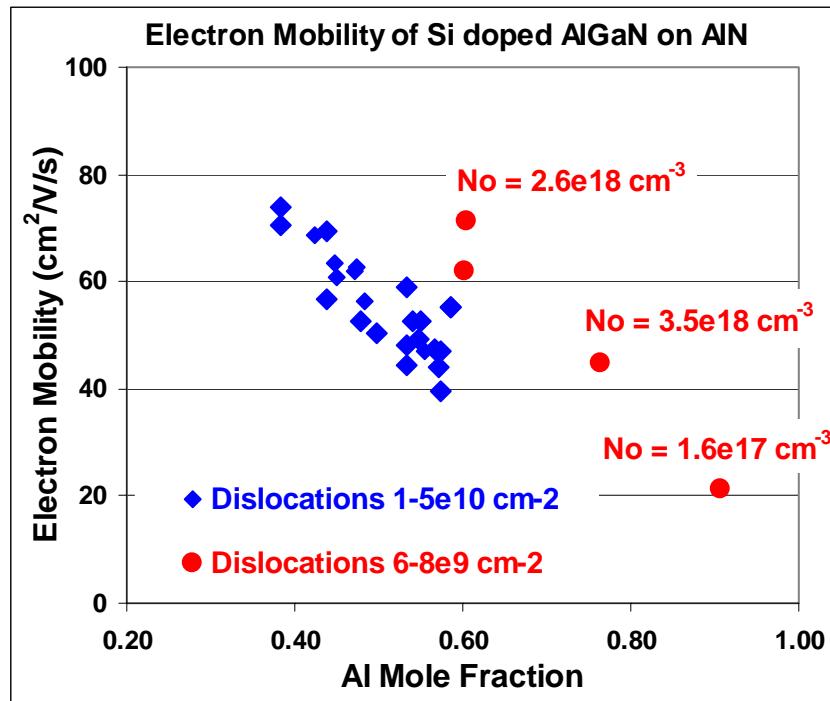


Figure 1. Electron mobility determined from Hall measurements of Si doped AlGaN alloys as a function of Al composition and dislocation density is shown. An increase in mobility and SiH₄ doping efficiency is observed in alloys where the density of dislocations with an edge component is less than $1 \times 10^{10} \text{ cm}^{-2}$. The electron concentration (No) of selected samples is shown.

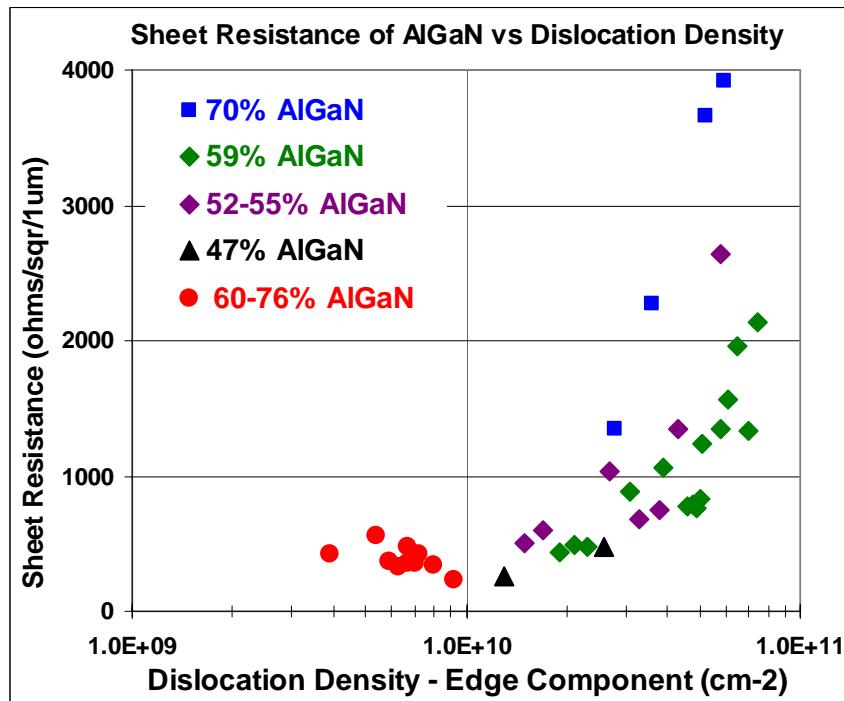


Figure 2. The normalized sheet resistance of the Si-doped AlGaN layer used in various LEDs as a function of dislocation density of dislocations with an edge component.